

Readout and electronics considerations for a detector at CLIC

Eva Sicking (CERN)
on behalf of the CLICdp collaboration

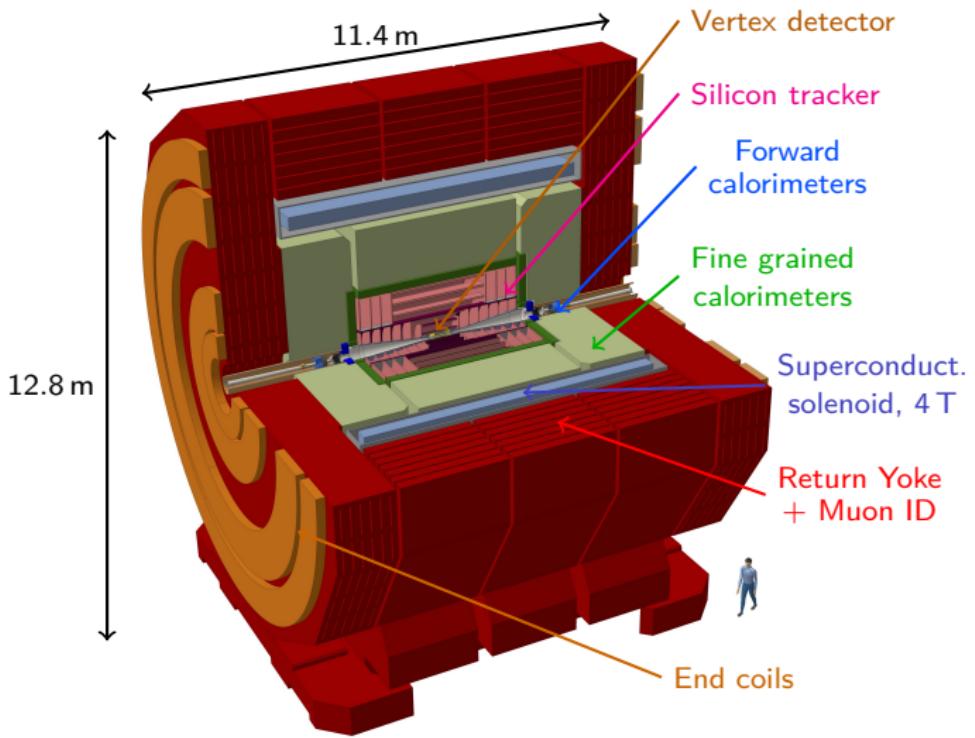
CLIC Detector & Physics Advisory Board
April 18, 2018

Disclaimer



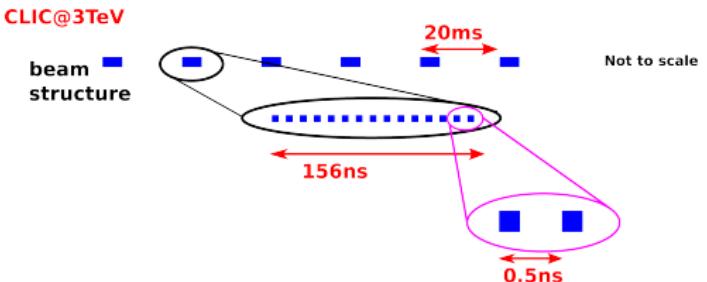
- ▶ Provide overview of **readout** and **electronics** for a CLIC detector
- ▶ Many numbers represent our current estimates
- ▶ The numbers are used to **define priority areas for R&D**
- ▶ After CLIC approval, start detailed studies of all areas

Data rates at CLIC



- ▶ **Silicon pixel and strip detectors:**
 - ▶ Measurement of arrival time (TOA) and time-over-threshold (TOT) for one hit readout per bunch train
 - ▶ Zero suppression is applied
- ▶ **Calorimeters:**
 - ▶ Sampling of pulse height at regular intervals
 - ▶ The required time resolution is achieved by signal shape analysis
 - ▶ No zero suppression is applied
- ▶ **Muon detectors:**
 - ▶ Digital readout with a multi-hit TDC
 - ▶ Zero suppression is applied as well as address decoding

Beam structure of CLIC



- ▶ Linear colliders operate in bunch trains
 - 1) Bunch separation and background particles drive timing requirement of detector
 - ▶ 10 ns hit time-stamping in tracking
 - ▶ 1 ns accuracy for calorimeter hits

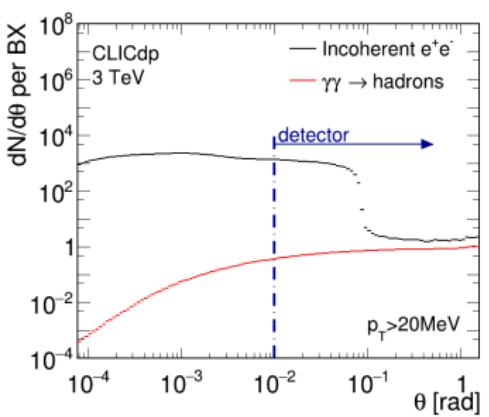
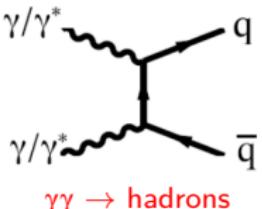
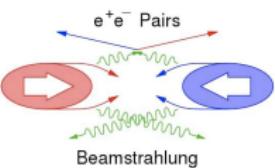
Property \sqrt{s}	380 GeV	1.5 and 3 TeV
Train repetition rate	50 Hz	50 Hz
Bunches / train	356	312
Train duration	178 ns	156 ns
Bunch separation	0.5 ns	0.5 ns
Duty cycle	0.00089%	0.00078%

2) Low duty cycle → Possibility of power pulsing of detectors

Beam-induced backgrounds at CLIC



- Achieve high luminosities at CLIC by using extremely small beam sizes
→ 3 TeV ("worst case"): Bunch size: $\sigma_{x;y;z} = \{40 \text{ nm}; 1 \text{ nm}; 44 \mu\text{m}\}$
→ very high E-fields → **beam-beam interactions:**



- Background particles
- Reduces \sqrt{s}

Main backgrounds ($p_T > 20 \text{ MeV}, \theta > 7.3^\circ$)

- **Incoherent e^+e^- pairs:**
 - 17.0k particles / bunch train at 3 TeV
 - High occupancies → **Impact on detector granularity and design**
- **$\gamma\gamma \rightarrow \text{hadrons}$**
 - 17.4k particles / bunch train at 3 TeV
 - Main background in calorimeters and trackers → **Impact on detector granularity, design and physics meas.**

- ▶ For each bunch train, the sub-detectors are read out once (exception calorimeters), without the use of triggers
- ▶ Occupancy per bunch train should generally not exceed few % (exception calorimeters)
- ▶ Occupancies from beam induced backgrounds drive the detector granularity and layout

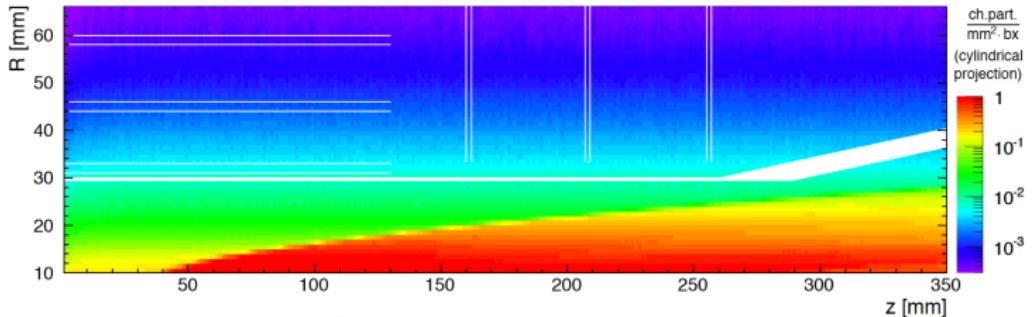
$$\text{Occupancy/train} = \sum_{\text{proc}} \text{Hits}_{\text{proc}} / (\text{mm}^2 \cdot \text{BX}) \times n_{\text{bunches}} \times p \times l \times cs \times sf_{\text{proc}}$$

- ▶ proc. = background process (e.g. incoherent $e^+ e^-$ pairs, $\gamma\gamma \rightarrow$ hadrons)
- ▶ BX = bunch crossing
- ▶ $n_{\text{bunches}} = 312$ bunch crossings per train at 3 TeV, spaced by 0.5 ns
- ▶ p = cell pitch, l = cell length
- ▶ cs = cluster size = average number of readout cells responding to each hit (e.g. 3 = tracker, 5 = vertex)
- ▶ sf = safety factor (2 for $\gamma\gamma \rightarrow$ hadrons, 5 for incoherent pairs)

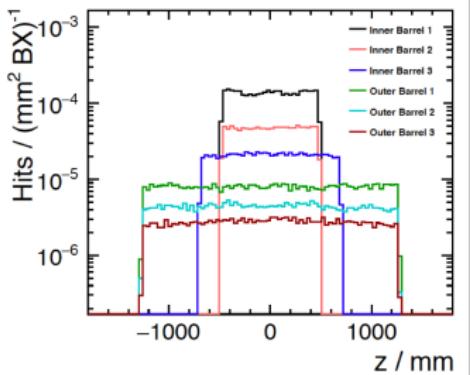
Example occupancies from beam-ind. bkg.



Vertex detector: Occupancy at 3 TeV, incoh. paris only, without safety factors Source: ▶ CDR



Tracking detector: Occupancy at 3 TeV,
without safety factors (barrel)



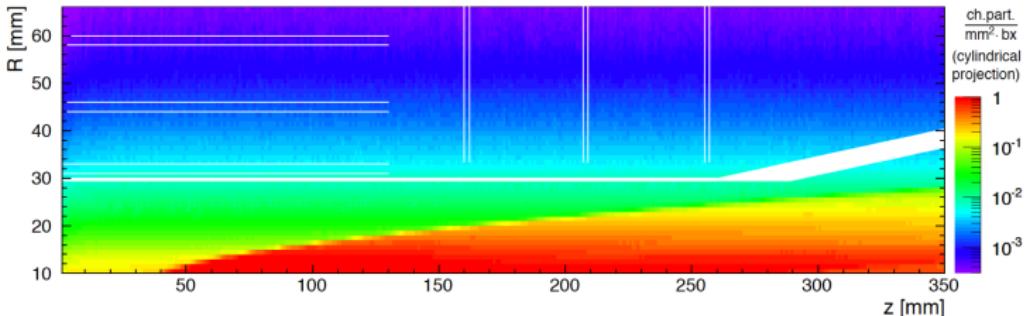
- ▶ Charged-particle densities from beam-induced backgrounds
- ▶ Adapt detector granularity to particle densities from beam-induced backgrounds

Source: ▶ CLICdp-Note-2017-002

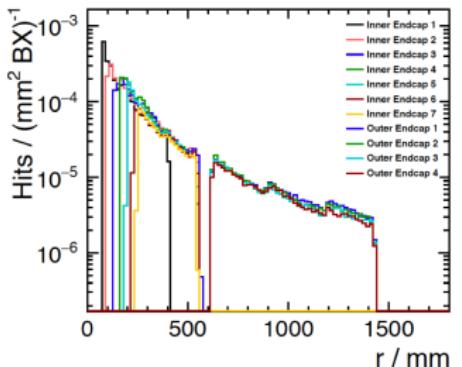
Example occupancies from beam-ind. bkg.



Vertex detector: Occupancy at 3 TeV, incoh. paris only, without safety factors Source: ▶ CDR



Tracking detector: Occupancy at 3 TeV,
without safety factors (disks)



- ▶ Charged-particle densities from beam-induced backgrounds
- ▶ Adapt detector granularity to particle densities from beam-induced backgrounds

Source: ▶ CLICdp-Note-2017-002

CLIC detector: data rates at 3 TeV



Strip-tracker geometry

				Number without safety factors, * Worst case without zero suppression			
	time sampling period	hit time stamping resolution	cell size	number of channels	average to maximum train occupancy	number of bits per cell	data volume *
	[ns]	[ns]	[mm ²]	[10 ⁶]	[%]	[bit]	[MByte]
VTX barrel	10	~ 5	0.025 × 0.025	780	0.5 - 3	13,1	110
VTX disks	10	~ 5	0.025 × 0.025	560	0.005 - 3	13,1	75
Inner Tracker Barrel 1	10	~ 5	0.05 × 1	16	0.4 - 1.6	22,1	2
Inner Tracker Barrel 2	10	~ 5	0.05 × 1	44	0.1 - 0.6	22,1	6
Inner Tracker Barrel 3	10	~ 5	0.05 × 5	21	0.3 - 1.7	22,1	3
Outer Tracker Barrel 1	10	~ 5	0.05 × 10	29	0.4 - 1.3	22,1	4
Outer Tracker Barrel 2	10	~ 5	0.05 × 10	41	0.2 - 0.8	22,1	5
Outer Tracker Barrel 3	10	~ 5	0.05 × 10	52	0.1 - 0.6	22,1	7
Inner Tracker Disk 1	10	~ 5	0.025 × 0.025	2000	0.00006 - 0.008	13,1	267
Inner Tracker Disk 2	10	~ 5	0.05 × 1	46	0.003 - 0.2	22,1	6
Inner Tracker Disk 3	10	~ 5	0.05 × 1	44	0.003 - 0.17	22,1	6
Inner Tracker Disk 4	10	~ 5	0.05 × 1	42	0.003 - 0.15	22,1	5
Inner Tracker Disk 5	10	~ 5	0.05 × 1	40	0.002 - 0.14	22,1	5
Inner Tracker Disk 6	10	~ 5	0.05 × 1	38	0.002 - 0.05	22,1	5
Inner Tracker Disk 7	10	~ 5	0.05 × 1	36	0.002 - 0.03	22,1	5
Outer Tracker Disk 1	10	~ 5	0.05 × 10	27.8	0.002 - 0.1	22,1	4
Outer Tracker Disk 2	10	~ 5	0.05 × 10	27.8	0.002 - 0.1	22,1	4
Outer Tracker Disk 3	10	~ 5	0.05 × 10	27.8	0.002 - 0.1	22,1	4
Outer Tracker Disk 4	10	~ 5	0.05 × 10	27.8	0.002 - 0.1	22,1	4
ECAL barrel	25	1	5 × 5	72	< 5	16	2160
ECAL endcap	25	1	5 × 5	29	0.8 - 40	16	870
HCAL barrel	25	1	30 × 30	4.8	< 5	16	144
HCAL endcap	25	1	30 × 30	4.5	37 - 4800	16	135
HCAL rings	25	1	30 × 30	0.4	< 5	16	12
LumiCal	10	5	4 × 13-44	0.245	415 - 21810	32	35
BeamCal	10	5	8 × 8	0.093	12730 - 31200	32	13
MUON barrel	25	8	30 × 30	1.2	0.01 - 0.05	24	< 0.01
MUON endcap	25	8	30 × 30	1.7	0.12 - 10	24	< 0.01

CLIC detector: data rates at 3 TeV



Pixel-tracker geometry

				Number without safety factors,	* Worst case without zero suppression		
	time sampling period	hit time stamping resolution	cell size	number of channels	average to maximum train occupancy	number of bits per cell	data volume *
	[ns]	[ns]	[mm ²]	[10 ⁶]	[%]	[bit]	[MByte]
VTX barrel	10	~ 5	0.025 × 0.025	780	0.5 - 3	13,1	110
VTX disks	10	~ 5	0.025 × 0.025	560	0.005 - 3	13,1	75
Inner Tracker Barrel 1	10	~ 5	0.03 × 0.3	88	0.06 - 0.3	22,1	11
Inner Tracker Barrel 2	10	~ 5	0.03 × 0.3	244	0.02 - 0.1	22,1	31
Inner Tracker Barrel 3	10	~ 5	0.03 × 0.3	580	0.01 - 0.06	22,1	72
Outer Tracker Barrel 1	10	~ 5	0.03 × 0.3	1589	0.01 - 0.02	22,1	199
Outer Tracker Barrel 2	10	~ 5	0.03 × 0.3	2258	0.004 - 0.01	22,1	283
Outer Tracker Barrel 3	10	~ 5	0.03 × 0.3	2893	0.002 - 0.01	22,1	362
Inner Tracker Disk 1	10	~ 5	0.025 × 0.025	2000	0.00006 - 0.008	13,1	267
Inner Tracker Disk 2	10	~ 5	0.03 × 0.3	252	0.0005 - 0.04	22,1	32
Inner Tracker Disk 3	10	~ 5	0.03 × 0.3	244	0.0005 - 0.03	22,1	31
Inner Tracker Disk 4	10	~ 5	0.03 × 0.3	228	0.0005 - 0.03	22,1	29
Inner Tracker Disk 5	10	~ 5	0.03 × 0.3	218	0.0004 - 0.02	22,1	27
Inner Tracker Disk 6	10	~ 5	0.03 × 0.3	208	0.0003 - 0.008	22,1	26
Inner Tracker Disk 7	10	~ 5	0.03 × 0.3	202	0.0003 - 0.005	22,1	25
Outer Tracker Disk 1	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
Outer Tracker Disk 2	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
Outer Tracker Disk 3	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
Outer Tracker Disk 4	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
ECAL barrel	25	1	5 × 5	72	< 5	16	2160
ECAL endcap	25	1	5 × 5	29	0.8 - 40	16	870
HCAL barrel	25	1	30 × 30	4.8	< 5	16	144
HCAL endcap	25	1	30 × 30	4.5	37 - 4800	16	135
HCAL rings	25	1	30 × 30	0.4	< 5	16	12
LumiCal	10	5	4 × 13-44	0.245	415 - 21810	32	35
BeamCal	10	5	8 × 8	0.093	12730 - 31200	32	13
MUON barrel	25	8	30 × 30	1.2	0.01 - 0.05	24	< 0.01
MUON endcap	25	8	30 × 30	1.7	0.12 - 10	24	< 0.01

Data volume at CLIC compared to LHC



Detector	Event size [MByte]	Repetition rate [Hz]	Data volumne [GByte/s]
CLICdet (strip tracker)	4 000	50	(train)
CLICdet (pixel tracker)	6 000	50	(train)
ATLAS / CMS (pp)	~ 1	100 000	(L1)
ALICE (PbPb) Run 3	70	50 000	(no trig.)

- ▶ mix: Combination of minimum bias, central, and muon events

- ▶ Number of optical data links needed for CLICdet readout
 - ▶ Active development of optical data links: prediction of bandwidth of O(20 Gbit/s) for time beyond 2025
 - ▶ Conservatively assuming optical data link **bandwidth of 10 Gbit/s**, CLICdet readout achievable with **160–240 links**
 - ▶ CMS detector is read out using 80 000 links

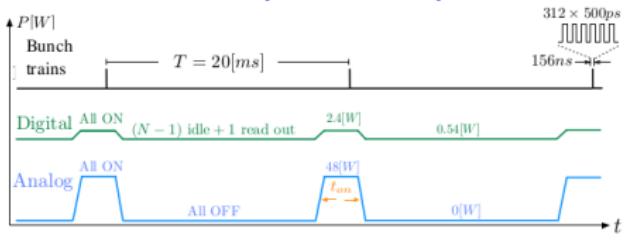
Electronics: Power delivery and power pulsing at CLIC

Power delivery & pulsing: Concept



- ▶ Small duty cycle of CLIC machine: 0.00078% @ 3 TeV
→ Turn off front end in gaps between bunch trains, to reduce average power
- ▶ Power-delivery & -pulsing concept optimised for low material budget

Vertex detector power consumption

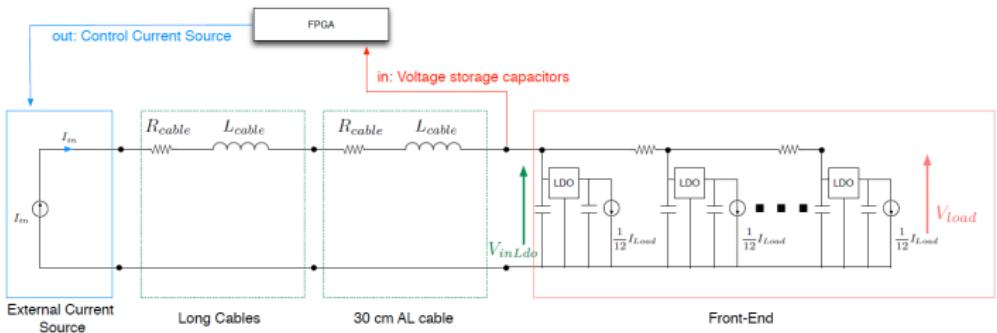


Example vertex detector:

▶ CLICdp-Note-2015-004

- Local energy storage in Si capacitors and voltage regulation with Low-Dropout Regulators (LDO)
- FPGA-controlled current source provides small continuous current
- Low-mass Al-Kapton cables

Power-delivery and power-pulsing design for low mass

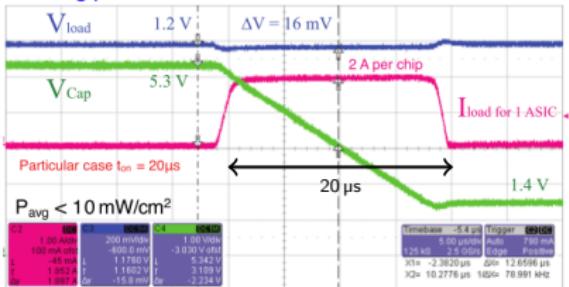


Power delivery & pulsing: Results

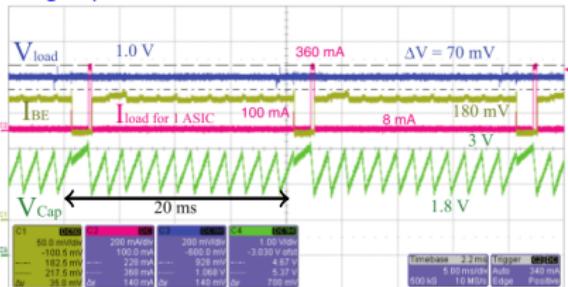


- ▶ Measurements on prototypes for digital and analog powering of vertex detector ladders
- ▶ Analogue
 - ▶ Voltage drop ~ 16 mV
 - ▶ Measured average power dissipation < 10 mW/cm²
- ▶ Digital
 - ▶ Voltage drop ~ 70 mV
 - ▶ Measured average power dissipation < 35 mW/cm²
- ▶ Total power dissipation < 50 mW/cm²

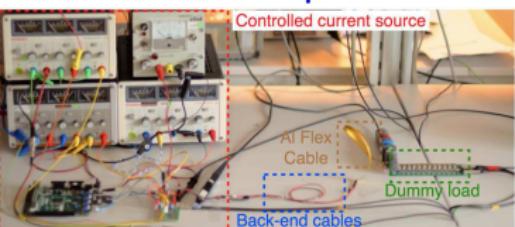
analog power



digital power



Test setup



Zoom: Analog dummy load PCB

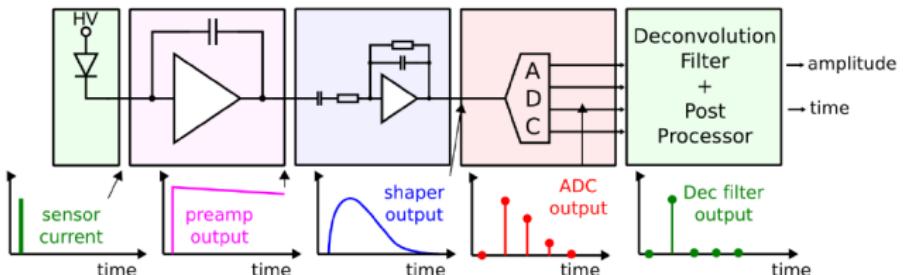


Electronics: Readout implementation

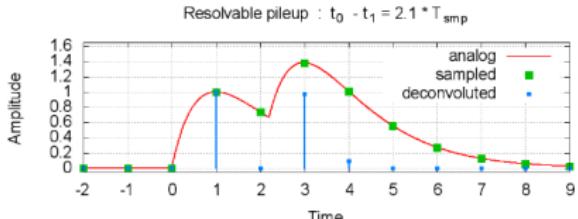
Example for calo.-readout implementation



Calorimeter readout electronics diagram ▶ LCD-Note-2011-015



- ▶ Sampling of pulse height at regular intervals: 25 ns (ECAL, HCAL) and 10 ns (LumiCal, BeamCal), no zero suppression
- ▶ Pulse at shaper output is convolution of input signal and impulse response of readout chain
- ▶ Using data from continuously running ADC and taking advantage of known pulse shape, deconvolute information about event time and amplitude
- ▶ Dealing with multiple energy deposits:
 - Two events can be separated and precisely measured if they have a time difference of $2-3 T_{\text{smp}}$



- ▶ Data rates at CLIC
 - ▶ Large event sizes at CLIC (4-6 GByte per bunch train) are compensated by low train frequency (50 Hz) → at most 300 GByte/s
 - ▶ Technology projections of optical data links indicates that the readout at CLIC can be achieved with few hundred optical data links
- ▶ Examples of electronics developments
 - ▶ Power delivery and pulsing concepts optimised for low material budget
 - ▶ Readout implementations under study for calorimeter as well as for vertex/tracking detectors



Backup

CLIC_ILD readout (CDR)



Number without safety factors

	hit time stamping resolution [ns]	time sampling period [ns]	cell size [mm ²]	number of channels [10 ⁶]	average to maximum train occupancy [%]	number of bits per hit [bit]	data volume [MByte]
VTX barrel	~ 5	10	0.02×0.02	945	< 1.5 - 1.9	32	56
VTX endcap	~ 5	10	0.02×0.02	895	< 2.0 - 2.8	32	72
FTD pixels	~ 5	10	0.02×0.02	1570	0.1 - 1.0	32	6.3
FTD strips	~ 5	10 - 25	0.05×100	1.6	160 - 290	16	48
SIT	~ 5	10 - 25	0.05×90	1.0	100 - 174	16	30
SET	~ 5	10 - 25	0.05×438	5.0	17 - 17	16	150
ETD	~ 5	10 - 25	0.05×300	4.0	38 - 77	16	120
TPC	^a	25	1×6	^b	5 - 32	24	500
ECAL barrel	1	25	5×5	69.5	< 3	16	2090
ECAL endcap	1	25	5×5	43.2	60 - 150	16	1300
HCAL barrel	1	25	30×30	6.9	< 5	16	210
HCAL endcap	1	25	30×30	1.8	120 - 5200	16	54
HCAL rings	1	25	30×30	0.2	< 5	16	6.0
LumiCal	5	10	5×5	0.2	600 - 6000	32	28
BeamCal	5	10	8×8	0.1	15600^c	32	15
MUON barrel	1	25	30×30	1.4	0.01 - 0.05	24	< 0.01
MUON endcap	1	25	30×30	2.4	0.12 - 10	24	< 0.01

a By combining with different subdetectors in offline reconstruction 2 ns will be achieved.

b The 3D TPC reads out 1000 voxels per channel for each bunch train.

c All cells measure a signal for each bunch crossing.

CLIC detector: data rates at 380 GeV



Strip-tracker geometry

				Number without safety factors, * Worst case without zero suppression			
	time sampling period	hit time stamping resolution	cell size	number of channels	average to maximum train occupancy	number of bits per cell	data volume *
	[ns]	[ns]	[mm ²]	[10 ⁶]	[%]	[bit]	[MByte]
VTX barrel	10	~ 5	0.025 × 0.025	780	0.1 - 1	13,1	107
VTX disks	10	~ 5	0.025 × 0.025	560	0.001 - 1	13,1	75
Inner Tracker Barrel 1	10	~ 5	0.05 × 1	16	0.08 - 0.6	22,1	2
Inner Tracker Barrel 2	10	~ 5	0.05 × 1	44	0.04 - 0.3	22,1	6
Inner Tracker Barrel 3	10	~ 5	0.05 × 5	21	0.08 - 0.7	22,1	3
Outer Tracker Barrel 1	10	~ 5	0.05 × 10	29	0.1 - 0.6	22,1	4
Outer Tracker Barrel 2	10	~ 5	0.05 × 10	41	0.07 - 0.3	22,1	5
Outer Tracker Barrel 3	10	~ 5	0.05 × 10	52	0.04 - 0.2	22,1	7
Inner Tracker Disk 1	10	~ 5	0.025 × 0.025	2000	0.00001 - 0.003	13,1	267
Inner Tracker Disk 2	10	~ 5	0.05 × 1	46	0.0006 - 0.08	22,1	6
Inner Tracker Disk 3	10	~ 5	0.05 × 1	44	0.0006 - 0.04	22,1	6
Inner Tracker Disk 4	10	~ 5	0.05 × 1	42	0.0006 - 0.04	22,1	5
Inner Tracker Disk 5	10	~ 5	0.05 × 1	40	0.0004 - 0.04	22,1	5
Inner Tracker Disk 6	10	~ 5	0.05 × 1	38	0.0003 - 0.02	22,1	5
Inner Tracker Disk 7	10	~ 5	0.05 × 1	36	0.0002 - 0.01	22,1	5
Outer Tracker Disk 1	10	~ 5	0.05 × 10	27.8	0.0005 - 0.04	22,1	4
Outer Tracker Disk 2	10	~ 5	0.05 × 10	27.8	0.0005 - 0.05	22,1	4
Outer Tracker Disk 3	10	~ 5	0.05 × 10	27.8	0.0004 - 0.04	22,1	4
Outer Tracker Disk 4	10	~ 5	0.05 × 10	27.8	0.0004 - 0.04	22,1	4
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ECAL endcap	25	1	5 × 5	29	0.2 - 5.8	16	870
HCAL barrel	25	1	30 × 30	4.8	< 5	16	144
HCAL endcap	25	1	30 × 30	4.5	25 - 4000	16	135
HCAL rings	25	1	30 × 30	0.4	< 5	16	12
LumiCal	10	5	4 × 13-44	0.245	106 - 8900	32	35
BeamCal	10	5	8 × 8	0.093	7625 - 35600	32	13
MUON barrel	25	8	30 × 30	1.2	0.01 - 0.05	24	< 0.01
MUON endcap	25	8	30 × 30	1.7	0.12 - 10	24	< 0.01

CLIC detector: data rates at 3 TeV



Strip-tracker geometry

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MUON barrel	25	8	30 × 30	1.2	0.01 - 0.05	24	< 0.01
MUON endcap	25	8	30 × 30	1.7	0.12 - 10	24	< 0.01

CLIC detector: data rates at 380 GeV



Pixel-tracker geometry

				Number without safety factors, *Worst case without zero suppression			
	time sampling period	hit time stamping resolution	cell size [mm ²]	number of channels [10 ⁶]	average to maximum train occupancy [%]	number of bits per cell [bit]	data volume * [MByte]
VTX barrel	10	~ 5	0.025 × 0.025	780	0.1 - 1	13,1	105
VTX disks	10	~ 5	0.025 × 0.025	560	0.001 - 1	13,1	75
Inner Tracker Barrel 1	10	~ 5	0.03 × 0.3	88	0.02 - 0.1	22,1	11
Inner Tracker Barrel 2	10	~ 5	0.03 × 0.3	244	0.007 - 0.05	22,1	31
Inner Tracker Barrel 3	10	~ 5	0.03 × 0.3	580	0.003 - 0.02	22,1	72
Outer Tracker Barrel 1	10	~ 5	0.03 × 0.3	1589	0.002 - 0.01	22,1	199
Outer Tracker Barrel 2	10	~ 5	0.03 × 0.3	2258	0.001 - 0.006	22,1	282
Outer Tracker Barrel 3	10	~ 5	0.03 × 0.3	2893	0.0008 - 0.004	22,1	362
Inner Tracker Disk 1	10	~ 5	0.025 × 0.025	2000	0.00001 - 0.003	13,1	267
Inner Tracker Disk 2	10	~ 5	0.03 × 0.3	252	0.0001 - 0.01	22,1	32
Inner Tracker Disk 3	10	~ 5	0.03 × 0.3	244	0.0001 - 0.008	22,1	31
Inner Tracker Disk 4	10	~ 5	0.03 × 0.3	228	0.0001 - 0.008	22,1	29
Inner Tracker Disk 5	10	~ 5	0.03 × 0.3	218	0.00008 - 0.008	22,1	27
Inner Tracker Disk 6	10	~ 5	0.03 × 0.3	208	0.00005 - 0.003	22,1	26
Inner Tracker Disk 7	10	~ 5	0.03 × 0.3	202	0.00005 - 0.002	22,1	25
Outer Tracker Disk 1	10	~ 5	0.03 × 0.3	1546	0.000008 - 0.0006	22,1	193
Outer Tracker Disk 2	10	~ 5	0.03 × 0.3	1546	0.000008 - 0.0008	22,1	193
Outer Tracker Disk 3	10	~ 5	0.03 × 0.3	1546	0.000008 - 0.0007	22,1	193
Outer Tracker Disk 4	10	~ 5	0.03 × 0.3	1546	0.000008 - 0.0007	22,1	193
ECAL barrel	25	1	5 × 5	72	< 5	16	2160
ECAL endcap	25	1	5 × 5	29	0.2 - 5.8	16	870
HCAL barrel	25	1	30 × 30	4.8	< 5	16	144
HCAL endcap	25	1	30 × 30	4.5	25 - 4000	16	135
HCAL rings	25	1	30 × 30	0.4	< 5	16	12
LumiCal	10	5	4 × 13-44	0.245	106 - 8900	32	35
BeamCal	10	5	8 × 8	0.093	7625 - 35600	32	13
MUON barrel	25	8	30 × 30	1.2	0.01 - 0.05	24	< 0.01
MUON endcap	25	8	30 × 30	1.7	0.12 - 10	24	< 0.01

CLIC detector: data rates at 3 TeV



Pixel-tracker geometry

				Number without safety factors, * Worst case without zero suppression			
	time sampling period	hit time stamping resolution	cell size	number of channels	average to maximum train occupancy	number of bits per cell	data volume *
	[ns]	[ns]	[mm ²]	[10 ⁶]	[%]	[bit]	[MByte]
VTX barrel	10	~ 5	0.025 × 0.025	780	0.5 - 3	13,1	110
VTX disks	10	~ 5	0.025 × 0.025	560	0.005 - 3	13,1	75
Inner Tracker Barrel 1	10	~ 5	0.03 × 0.3	88	0.06 - 0.3	22,1	11
Inner Tracker Barrel 2	10	~ 5	0.03 × 0.3	244	0.02 - 0.1	22,1	31
Inner Tracker Barrel 3	10	~ 5	0.03 × 0.3	580	0.01 - 0.06	22,1	72
Outer Tracker Barrel 1	10	~ 5	0.03 × 0.3	1589	0.01 - 0.02	22,1	199
Outer Tracker Barrel 2	10	~ 5	0.03 × 0.3	2258	0.004 - 0.01	22,1	283
Outer Tracker Barrel 3	10	~ 5	0.03 × 0.3	2893	0.002 - 0.01	22,1	362
Inner Tracker Disk 1	10	~ 5	0.025 × 0.025	2000	0.00006 - 0.008	13,1	267
Inner Tracker Disk 2	10	~ 5	0.03 × 0.3	252	0.0005 - 0.04	22,1	32
Inner Tracker Disk 3	10	~ 5	0.03 × 0.3	244	0.0005 - 0.03	22,1	31
Inner Tracker Disk 4	10	~ 5	0.03 × 0.3	228	0.0005 - 0.03	22,1	29
Inner Tracker Disk 5	10	~ 5	0.03 × 0.3	218	0.0004 - 0.02	22,1	27
Inner Tracker Disk 6	10	~ 5	0.03 × 0.3	208	0.0003 - 0.008	22,1	26
Inner Tracker Disk 7	10	~ 5	0.03 × 0.3	202	0.0003 - 0.005	22,1	25
Outer Tracker Disk 1	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
Outer Tracker Disk 2	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
Outer Tracker Disk 3	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
Outer Tracker Disk 4	10	~ 5	0.03 × 0.3	1546	0.00004 - 0.002	22,1	193
ECAL barrel	25	1	5 × 5	72	< 5	16	2160
ECAL endcap	25	1	5 × 5	29	0.8 - 40	16	870
HCAL barrel	25	1	30 × 30	4.8	< 5	16	144
HCAL endcap	25	1	30 × 30	4.5	37 - 4800	16	135
HCAL rings	25	1	30 × 30	0.4	< 5	16	12
LumiCal	10	5	4 × 13-44	0.245	415 - 21810	32	35
BeamCal	10	5	8 × 8	0.093	12730 - 31200	32	13
MUON barrel	25	8	30 × 30	1.2	0.01 - 0.05	24	< 0.01
MUON endcap	25	8	30 × 30	1.7	0.12 - 10	24	< 0.01